



Railroad Perspective on Locomotive Exhaust Aftertreatment & Technology

**From idea to market:
technological successes & limitations**

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Union Pacific Railroad Company
CARB 4th Railroad Emission hearing
El Monte, California ~ November 28, 2007

Year 2007 retrospective: *CA loco. emissions*

- ➔ Progress continuing on 1998 and 2005 MOU goals
- ➔ 1st two US locos. retro'd with DPF, limited success
 - ⚡ 1 each Roseville and San Antonio
- ➔ 1st US loco. retro'd with oxidation catalyst, several failures
 - ⚡ in Los Angeles Basin
- ➔ Next EPA locomotive emissions regulation being finalized
- ➔ Largest single fleet of ULEL genset switchers now working in LA
 - ⚡ 9% reduction in all (total) loco. emissions within SCNA
- ➔ ULEL hybrid switchers temporarily withdrawn from LA service
 - ⚡ Now being re-commissioned
 - ⚡ 2% reduction in SCNA loco. emissions



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Technological paths: *loco. aftertreatment*

→ Technological progress: North American & European Union

⚡ US ~21,000 diesel locomotives, EU ~ 17,000 diesel locomotives (+14,000 diesel passenger rail cars)



⚡ 112 locomotives with verified (tested) exhaust aftertreatment

- ~99 new applications, ~13 retrofits
- 3 in US, 109 in Europe



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Locos. w/ aftertreatment: *known population**

→ Existing (older) locomotives, retrofitted aftertreatment

- ⚡ 6 1200hp switchers: Switzerland (SBB Cargo) w/ DPF (particulate filter), ~3 years service
- ⚡ 4 1500hp switchers: UK/France (Eurotunnel) w/ DPF & urea-SCR (selective catalytic reduction of NOx), now being commissioned
- ⚡ 2 1500hp switchers: US (UP in Roseville & BNSF in San Antonio) w/ DPF, 1+ & <1 year service
- ⚡ 1 3800hp road unit: US (UP in LA) w/ DOC (diesel oxidation catalyst), 1 year service

→ New locomotives factory-equipped aftertreatment

- ⚡ 1 3600hp road unit: Germany/Sweden w/ DPF, ~3 years service
- ⚡ ~98 2000hp switchers: Switzerland (SBB Cargo & BLS), w/ DPF, 2-3 years service

* Locomotives in non-underground mining service; locomotives & aftertreatment have been subjected to some form of emissions testing to verify results



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Worldwide tech. assessment

→ Small numbers of locomotives with aftertreatment experience

⚡ 0.01% in US, 0.6% in EU

→ Very short in-service times

⚡ <1 year to 3+ years

→ Radically different operating environments

⚡ US v European

→ Limited pursuit by marketplace

⚡ US locomotive engine '07 market estimated to be

⚡ US "big 6" class 8 diesel engine '07 market

⚡ US aftertreatment industry heavily involved
in meeting EPA truck regulation

~1,350 } **1:237**
~320,000 } **ratio**



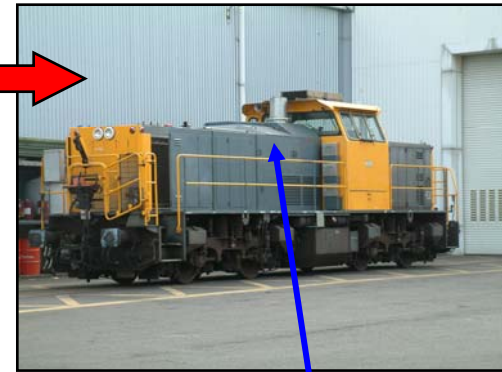
World's first DPF+SCR locomotive

→ Eurotunnel maintenance fleet

- ⚡ 4 1500hp switchers, 1990s design, night maintenance & “tunnel rescue”, double-tunnel railroad ~31 miles long
- ⚡ previously operated in pairs w/ water-scrubber “tenders” and exhaust ducts
- ⚡ now being overhauled with Hug DPF+SCR, 1st unit commissioned
- ⚡ *advertised 90% PM reduction, est. 70-90% reduction in NOx*



Charcoal water-scrubber tender, locomotive exhaust was ducted from units to both ends of scrubber car



Hug DPF+SCR inside carbody

SWRI and Union Pacific examined in November 2005



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1st US retrofits

→ UPY1378 & BNSF3703 with DPF

- ⚡ 1500hp EMD switchers, 1980s design

- ⚡ UP at Oakland 6 mos. & Roseville 6 mos., BNSF at SWRI test facility/shop

- ⚡ *Hug technology claimed 90% PM reduction; UP unit released from SWRI ~80% PM removal account blowby, BNSF unit now being retrofitted with DOC to boost DPF performance to 90%*



→ UP2368 with oxicat

- ⚡ 3800hp EMD road unit, 1990s design

- ⚡ UP inside Los Angeles basin since January 2007

- ⚡ Miratech technology, FTP tested at ~50% SOF reduction

- ⚡ *2 failures of catalytic panels in 11 months of operation, more redesign taking place*

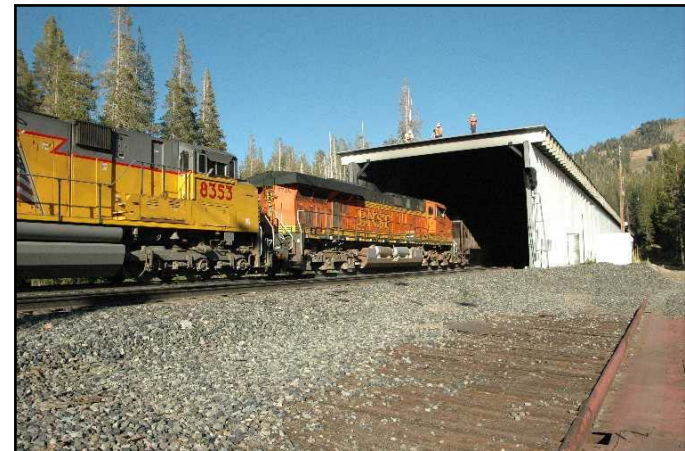
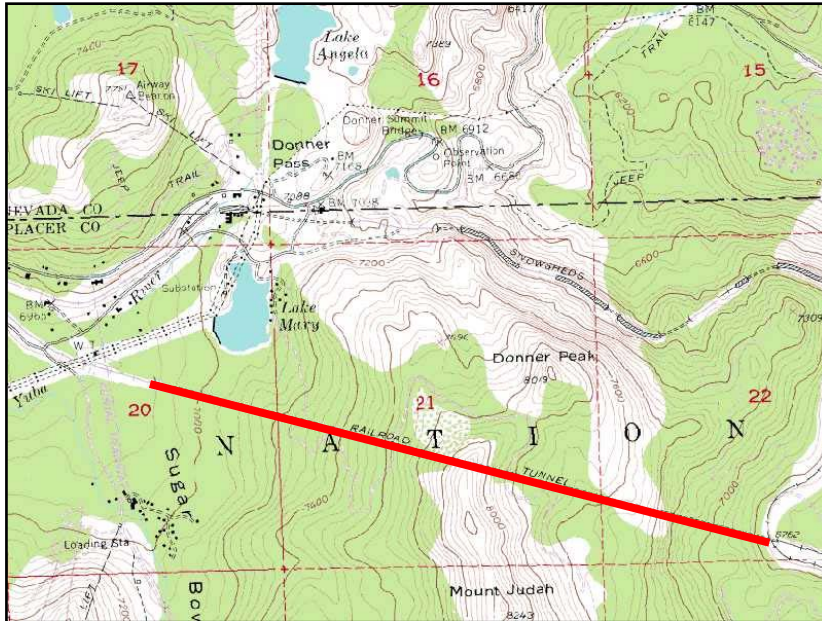


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EPA testing in US tunnel environment

➔ UP Tunnel 41, Donner Summit, August 2007

- ⚡ Instrumented Tier 2 units (EMD SD70ACe and GE ES44AC)
- ⚡ Severe test, heavily loaded train, 10,000' tunnel
- ⚡ Locomotive control systems sufficiently de-rated engines to avoid excessively-high exhaust temperatures (re risks to future catalytic elements)



New technologies (non-aftertreatment)

→ Ultra-low emitting “genset” switchers

⚡ UP now has 60-of-61 units (non-subsidized) in Los Angeles Basin operation

⚡ 61st unit left Chicago yesterday afternoon, ETA LA Basin this weekend

⚡ Non-aftertreated EPA Tier 3 off-road engines

- 80% reduction in NOx
- 90% reduction in PM
- 16-37% reduction in fuel use and GHG



⚡ ~9% reduction in all (total) locomotive emissions within SCNA resulting from these 61 units

⚡ UP awarded SAE 2006 “Environmental Excellence in Transportation” (E²T) award for mobility and engine emissions category (May 16, 2007)

- 2005 E²T winner was Honda (Accord hybrid)



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New technologies (non-aftertreatment)

→ Ultra-low emitting “hybrid (Green Goat)” switchers

⚡ UP acquired 10 hybrids for LA Basin (non-subsidized) in 2005

- All 10 hybrids (along with all other ~45 hybrids nationwide) removed from service in 2Q07 for battery problems, major modifications
- 10 UP LA hybrids being re-commissioned at City of Industry; 2 units now working at City yard, going back to Mira Loma within weeks
- UP remains committed to success of diesel-battery hybrid technology

⚡ 25 tons of batteries, single Tier 3 engine

- 90% reduction in NOx
- 90% reduction in PM
- 16-20% reduction in fuel use and GHG

⚡ ~2% reduction in all (total) locomotive emissions within SCNA resulting from these 10 units



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The loco. emissions “technology tunnel”



“With engineering, I view this year's failure as next year's opportunity to try it again.”

“Failures are not something to be avoided. You want to have them happen as quickly as you can so you can make progress rapidly.”

Gordon Moore



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